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STRUCTURAL STABILITY CONSIDERATIONS IN THE ROTOR SYSTEM OF THE HOT GAS JET HELICOPTER DO 132

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23

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ABSTRACT: The rotor system of a hot gas-jet helicopter (DO-132) is examined from the standpoint of resistance to vibration and stress on the structured system of the blades.

1. INTRODUCTION

The reliability of a rotor system depends upon the resistance of the individual components to vibration, and a high degree of safety is required of them. Indications of acceptable service life and safety as a service life requirement is only possible to a sufficient degree by testing under operational simulation. However, a successful result can hardly be achieved if consideration of structural stability cannot be applied during development. Every system has its own special stress situations, so that results from one rotor system can seldom be applied to another. This is particularly true of the rotor blade of the DO 132 helicopter, for which no comparable examples of construction are available. While the high frequency of impact bending and vibration bending stresses predominantly determine the service life for normal rotor systems, these stress magnitudes can be almost disregarded for the rotor blade of the DO 132 helicopter. Here the beginnings of basic loading in flight become decisive, /77*

*Numbers in the margin indicate pagination in the foreign text.

namely flight power changes and overlapping bending moments from the zero moments from the zero harmonic of impact bending.

This short report gives in broad lines a survey of the operating stress conditions of the DO 132 rotor system, especially of the rotor blade, as well as of the determination of the structural stability under special conditions.

2. Technical Structural Data of the Helicopter /79

2.1. Dimensions in Weight, See Figure 1

Total length	7.5 m	Empty weight	675 KP
Total height	2.9 m	Normal flying weight	1,430 KP
Fuselage width	1.4 m	Maximum take-off weight (with a jump start)	1,630 KP
Fuselage height	1.6 m		
Rotor diameter	10.7 m	Rotor blade weight	59 KP
Blade thickness	0.42 m		
Mean skid interval	2.2 m		

2.2. Other Data

Rotor angular velocities:	$\omega_{normal} = 36$ 1/s	(adjusted)
	$\omega_{max} = 45$ 1/s	(with jump start)
Hot gas temperature:	740°C (max)	
Gas pressure:	2 atm (max)	

2.3. Construction Description

The bearing bracing of the cell consists of a main frame lying behind the cabin, the rotor mast bearing plate attached to it and a bearing control shaft, as well as the lower longitudinal bearers to which the landing gear is attached. It has a regular riveted shell structure. The material used is the proven aluminum alloy AlCuMg 2, which is most suitable for vibration stressed constructions.

The construction of the rotor system is shown in Figure 2. The system is elastically attached to the rotor bearing plate of the cell with forces and moments transmitted by spring members. The hot gases of the drive assembly, developed as a gas producer, are conducted through the rigid rotor mast to the rotating rotor head from which the hot gases reach the blade ends through a thin-walled conduit made of heat-proof Nimonic 90 material floating in the rotor blades and drive the rotor blade. All heat conducting parts are made of heat-proof materials, chiefly alloy 1.4944 (A 286).

The main components of the central semi-rigid rotor system are:

Blade articulation with the hub (titanium alloy)
Longitudinal runners (aluminum alloy)
Blade support (aluminum alloy)
Blade hub (titanium alloy)

They are forged from proved materials, the operational behavior of which (resistance to vibration, rip migration and rip resistance) are subjected to rigorous testing in consideration of their importance to life.

The rotor blade, which carries the thin-walled hot gas conduits and the intermediate insulation inside itself, is produced in a sandwich-type construction of aluminum members glued together, see Figure 3. The casings of the sandwich structure must be made heat-proof by insulation because of the temperature incidence (maximum of about 130°C), and this is provided for by using aluminum alloy 2024-T62 or T81. In addition, a heat-proof adhesive system, with high strength factors and good creeping strength, is used. The developmental work for this is still in progress.

In order to absorb the increasing stress on the rotor blade root (see Figure 7) an increase in cross-sections is obtained by using a multilayer lamination, which at the same time gives the area a "fail-safe" character (see Figures 3 and 4).

The use of the aluminum alloy for the bearing blade body was made possible by using a high temperature insulation designated "MIN-K." With an insulation layer only 2.5 mm thick, we achieved a reduction in hot gas temperature from 740°C to a structural member temperature of 100-130°C, depending upon the ambient temperature, the rotational velocity and the region of the rotor.

Further details concerning the light helicopter can be obtained from published construction descriptions.

3. Principles of Measurement for the Structural Stability of the Rotor System

In order to achieve the demands levied in regard to service life, measurement in the direction of maximum loads is not usually appropriate for a rotor system. For this reason initial plans are drawn up for admissible unit operational stresses which make the construction goal achieveable. The basis for size determination is the profile of the flight vehicle. Since a large number of different kinds of assemblies are possible for these helicopters, a typical profile assembly must be assumed covering all possible assemblies sufficiently. The basic data for this typical case of assembly and for the hourly operational time aimed at are the following:

Operating hours:	1,000 h
Number of flights:	6,000
(or) mean flight length	10 min
Mean flight height:	400 m
Computed weight:	85% of maximum lift-off weight
($\cong$ average flight weight)	

Figure 5 shows the "typical assembly profile" used for the DO 132 ship, divided into eleven flight phases. A different determination of flight phases, such as recommended by the American Regulation CAM 6, Appendix A, is not reasonable for this rotor system, since most load cases provide a negligible contribution to damage (fatigue). A detailed investigation according to CAM 6 clearly showed that only the following load cases have any effect:

- Ground transportation
- Acceleration of rotor and starting (jump start)
- Cruising at 80% V_{NE}
- Manipulation of pitch and throttle
- Banking

Cruising at 80% V_{NE} is representative of all cruising conditions, i.e., hovering, descending and ascending flight. The manipulation case (pitch and throttle) covers all cases of load maneuver including landing approach.

4. Operational Stresses of the DO 132 Rotor System

The operating load conditions are divided into basic loads and breakdown loads. Basic load conditions are stationary load conditions such as standing on the ground and cruising at $n_z = 1.0$. Breakdown loads are those resulting from supplemental acceleration and these are superimposed upon the base load. Load distribution functions which are derived from loading statistics or flight measurements are currently assigned to breakdown loads, but the load distribution functions are only introduced when their maximum values are significant. Usually, in order to simplify insignificant load cases, a rectangular distribution is used with the maximum value determined. By using this method we remain on the safe side.

Figure 6 shows the load cases and collective forms chosen for the rotor blade, and here also simplifications have been assumed for some collective forms.

In order to be able to judge the structural stability of all segments of the rotor system it is necessary to determine the momentary stress collectives of the places considered for the load collectives defined in Figure 6, since the stress pattern changes across the blade length, see Figure 7. This research showed that the most stressed place lies on the extension of the panels on the bottom of the blade (segment 1435), where there must be an increase in stress because of the stress concentration derived from the jump in rigidity; this is difficult to compute.

This example shows the methodology used initially to obtain indications about the structural stability of the rotor system.

4.1. Stress Collectives of the Blade Bottom in Segment 1435 (See Figures 3 and 4)

Because of its gas conducting function, the rotor blade under discussion has a large cross-section and thus relatively large moments of inertia in the impact and vibration direction. This produces advantages for absorbing the moments. Thus, the flight power stress and its associated "quasistatic" impact bending is derived from the zero harmonic at a determinable magnitude.

As can be seen from Figure 8, the stress components from the flight power and the moments are very distinct. Therefore, it can be assumed that only the resulting maximum stresses from all individual components present a detrimental process, but not the very frequent impact moment of the second harmonic and of the moment of vibration in cruising. These breakdown stresses for this rotor blade are < 0.8 kp/mm^2, thus far below the fatigue strength level, and can thus be disregarded in reference to frequency. However, consideration of the low stress contribution in load lifting seems logical.

The stress collectives (see Figure 9) for the lamellar extension clearly show that an interaction of elastic and plastic deformations, which cause damage according to today's knowledge, can only occur through the maximum values in lo load changes at starting and landing and with maximum pitch and throttle maneuvers,

A computational estimate of the service life based on these collectives and on service life curves of similar materials by means of a modified damage accumulation hypothesis showed that low probabilities of failure, $P_\alpha < 10^{-5}$ are attainable.

Pretests and Test Indications

5.1. Preinvestigations

Determination of the service life of a structural component is predominantly possible only through testing. In this process the actual flight process must be simulated as thoroughly as possible. Naturally this is an enormous test technique problem with a rotor blade, and is very costly. For this reason, we are forced to look for representative simplifications in order to achieve results. In the case of the DO 132 rotor blade it was possible to use a greatly simplified test method in a pretest on a test blade; this showed that the significant weak point lies on the panel extension and that the operational stresses are applied by resulting normal forces. Still, this simplification has the disadvantage that the total cross-section of the unreinforced blade is stressed to a greater degree, since the local stress on the panel extension is forced upon the rest of the cross-section. Since in this blade the flight force provides the decisive contribution, this testing method is representative for the investigation of weak points.

5.2. Operating Test Program for the Test Blade

In order to simulate stresses in the test close to the operating stresses, the total collective must be divided in such a way that several types of flight show up with a corresponding frequency of appearance. The cumulative frequency of the individual flight types must correspond at least to the frequency of the total collective. For the DO 132 rotor blade four flight types were chosen. The gradation of the maneuver collective, see Figure 10, served as a basis for dividing the total collective. Figure 11 shows the example of a stress course in these four flight types which was simulated on the DO 132 rotor test blade by means of a hydropulse device made by the Schenk Company. This test blade contained the original blade attachment at both ends and was used to find weak points and to study the testing method. Valuable knowledge was able to be collected with this test and was put to use in the further development of the rotor blade and the test mehtodology. Thus it is indispensable, for example, to monitor the program controlled hydropulse device constantly by means of a recorder in order to have a control over the actual loading process.

After the termination of the final rotor blade construction, another test blade is subjected to this simplified testing method. The result of the test will show whether a distinctly different test method has to be selected to indicate the service life of the following test blades.

5.3. Other Rotor System Tests

Individual flight program tests are being prepared for all main structural components of the rotary system. Two investigations of elementary specimens have already been finished. One of the investigations had the purpose of determining the limiting values of resistance to vibration of the hot gas conduction pipe at 750° by spot checking, see Figures 13 and 14. The second investigation was concerned with the behavior of rip extension and the aluminum sandwich casing under simulated flight loading. As expected, this showed that material 2024-T62 is more favorable than T81. These results will be published in a later report.

The rotor testing stand already in operation, with which critical spots can be measured during test flight by DMS, provides important data, Figure 15.

6. Prospects

The writer hopes that after finishing his research on structural stability he can report to the DGLR-Specialty Committee "Rotating Wing Aircraft Airscrews" a thorough report of his results with a description of the entire field of problems of the DO 132 structural stability indications.

Discussion Contribution to the Lecture of Mr. Brenner, Dornier

The lecturer has given a survey of the operating stress and structural stability of the DO 132 rotor blade in a stage of development where flight operations are impossible and component tests are not available. He has wtated which load cases and stresses will be decisive for service life computation and said that, with the use of service life characteristics of similar (!) materials, low failure probabilities $< 10^{-5}$ are attainable.

The failure of a vitally important component is usually associated with the loss of the helicopter and with human victims. Therefore it is not enough to use as indications computed stresses and estimated ultimate stress values, but rather

1. There must be an extensive number of tests to determine the structural stability of the component.

2. Flight measurements in operation to determine the stresses occurring.

In practice it has proved valuable to begin the first-mentioned tests as early as possible. As soon as it is known what stresses the component can bear, it is possible to undertake risk-free flight tests, if certain limiting stresses, to be monitored in flight are determined from the test trials. Thus, the flight measurements referred to in Point 2 can be carried out with the least possible danger for men and material. The type and range of the flights must assure that all possible peak loads are contained in the measurements.

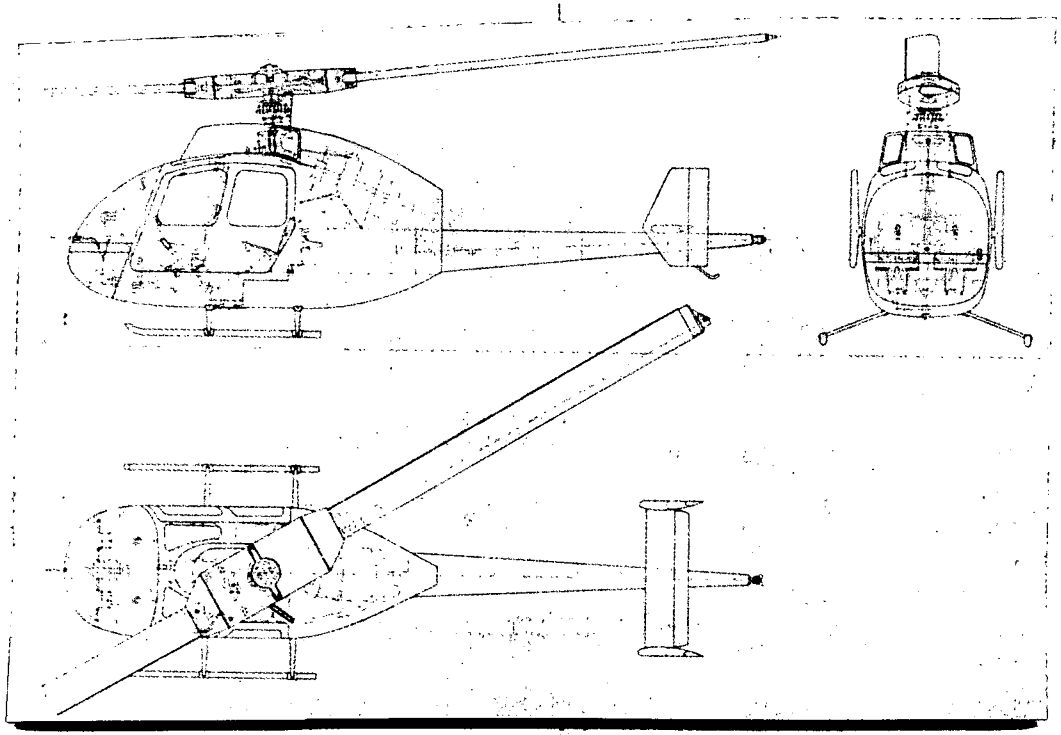

Figure 1. General Diagram of the Hot Gas Jet Helicopter DO 132.

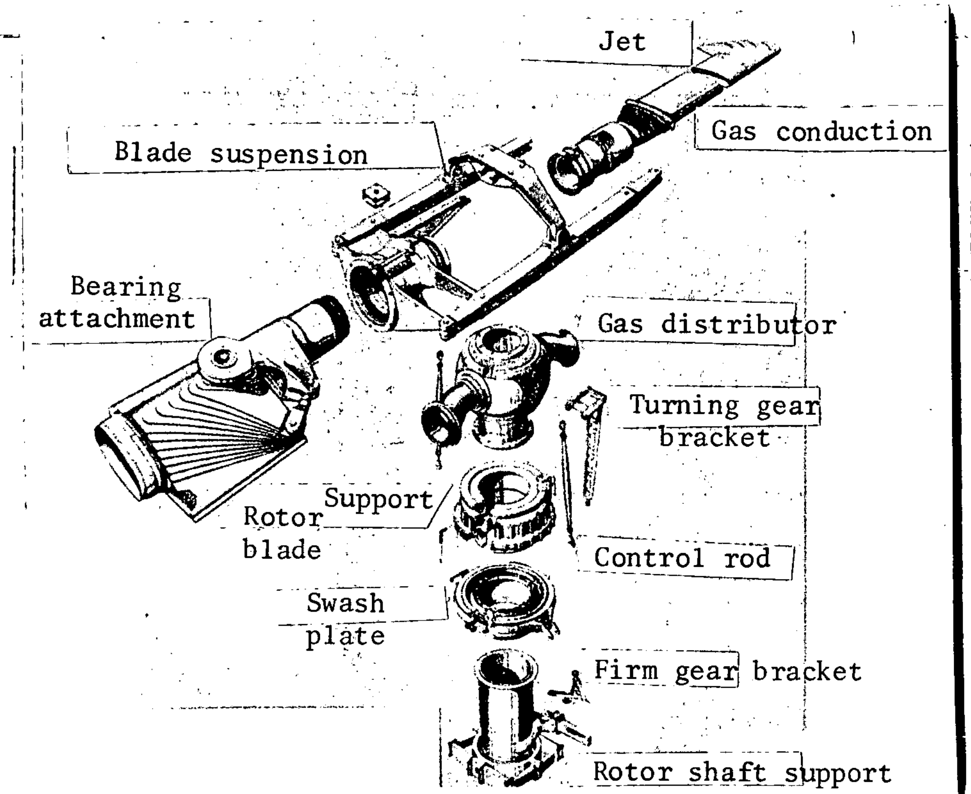

Figure 2. Construction of the DO 132 Rotor System.

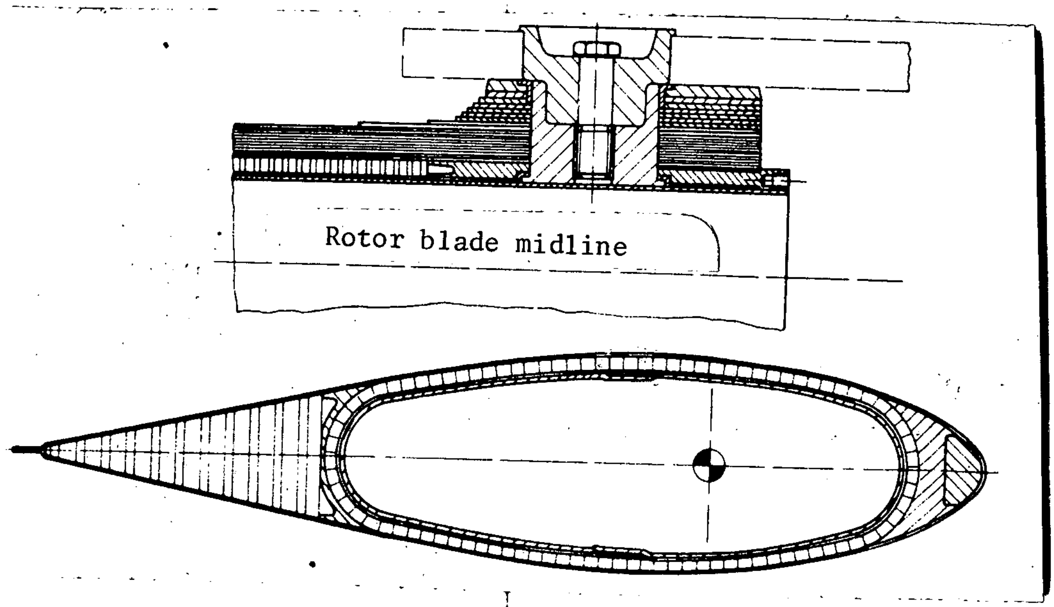

Figure 3. Cross-Section of DO 132 Rotor Blade.

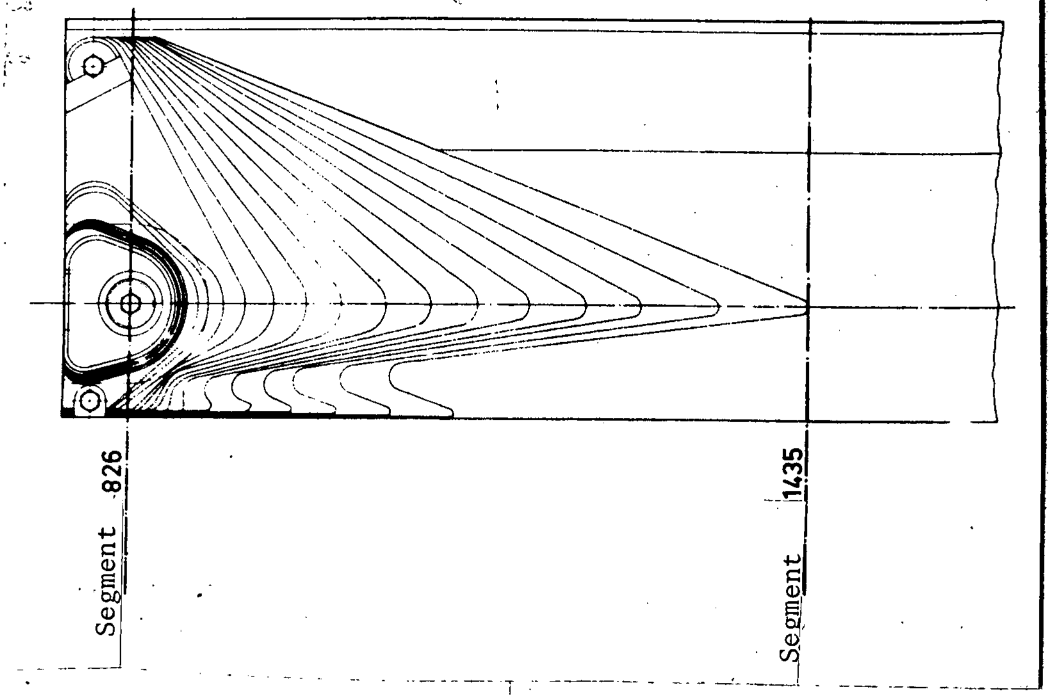

Figure 4. Multilayer Lamination on Blade Root.

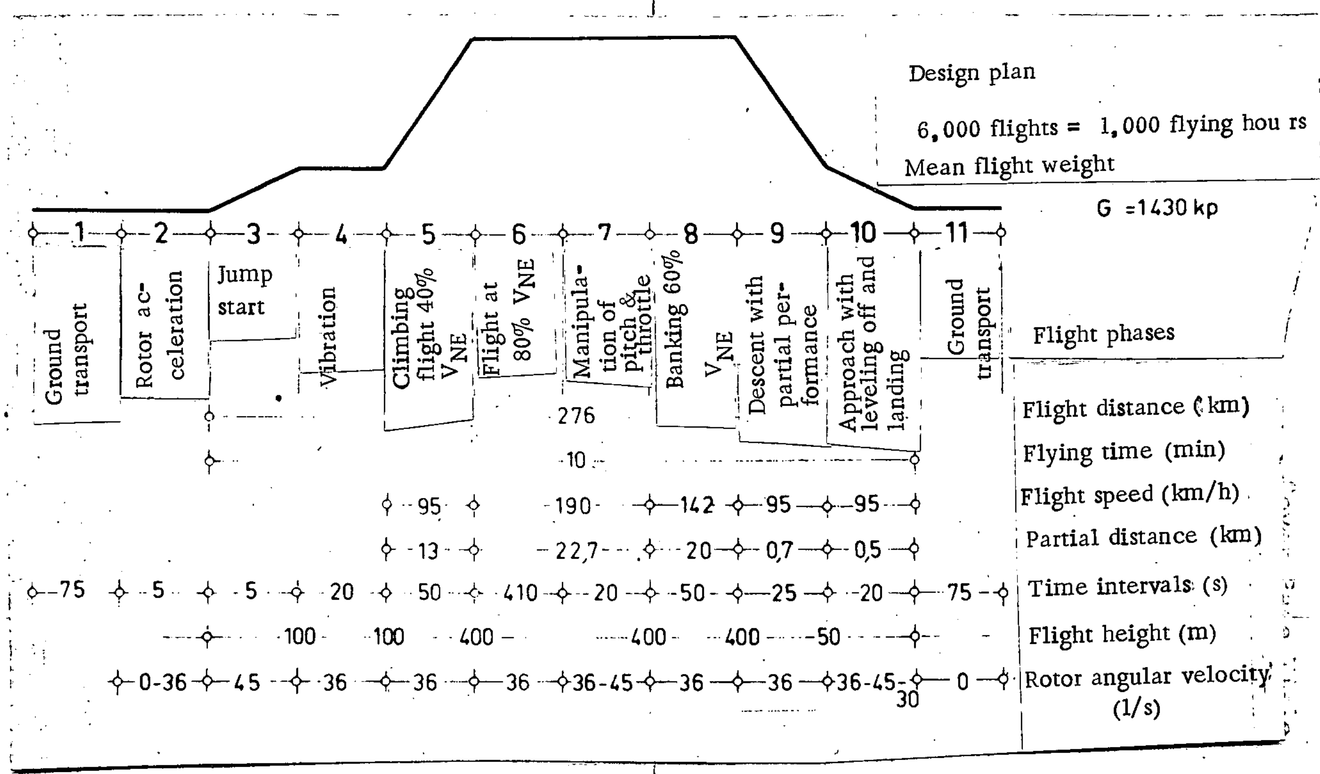

Figure 5. Typical Assembly Profile of DO 132.

Load case	Load		Frequency and Collective Form
1. Standing on ground	Impact moment 0 harmonic		-----
2. Cruising at 80% V_{NE}	Flight force ω = 36 Impact moments 0 & 2nd harmonic	Basic loads	-----
3. Ground transport	Impact moment 2nd harmonic		n = 300 LW/flight, LBF normal distribution replaced by 1LW/flight-rectangular distribution
4. Jump start	Flight force $\tilde{\omega}$ = 45 1/s Impact moment 0 harmonic	n_{max} = 2.6	n = 1LW/flight-rectangular distribution
5. Starting & landing load charge	Top loading from spring start-belly load from ground transportation		n = 1LW/flight-rectangular distribution
6. Banking	Flight force ω = 36 1/s Impact moment 0 harmonic	n = 1.9	n = 4LW/flight-rectangular distribution
7. Manipulation of pitch and throttle	Flight force: Zoom ω = 45 1/s n = 3.0 descent ω = 36 1/s n = -1.0 Impact moment 0 or 2nd harmonic		n = 10LW/flight- 0.36 LW/km straight line distribution
8. Vertical turbulence	Flight force ω = 36 1/s Impact moment 0 harmonic	V_{Bo} = 40 ft/s	n = 10LW/flight for V_{Bo} > > 10 ft/s log normal distribution

Figure 6. Operating Stresses on DO 132 Rotor Blade Top or Bottom.

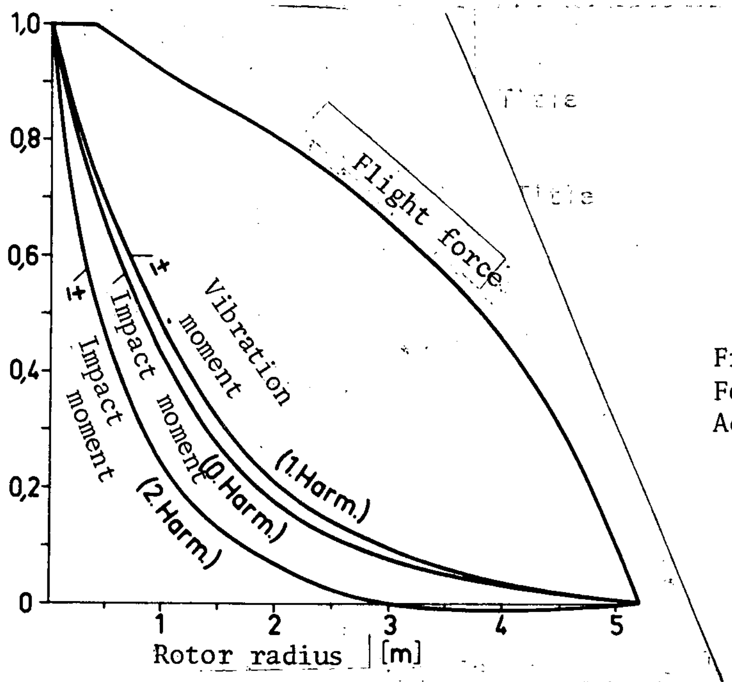

Figure 7. Course of Forces and Moments Across Blade Length.

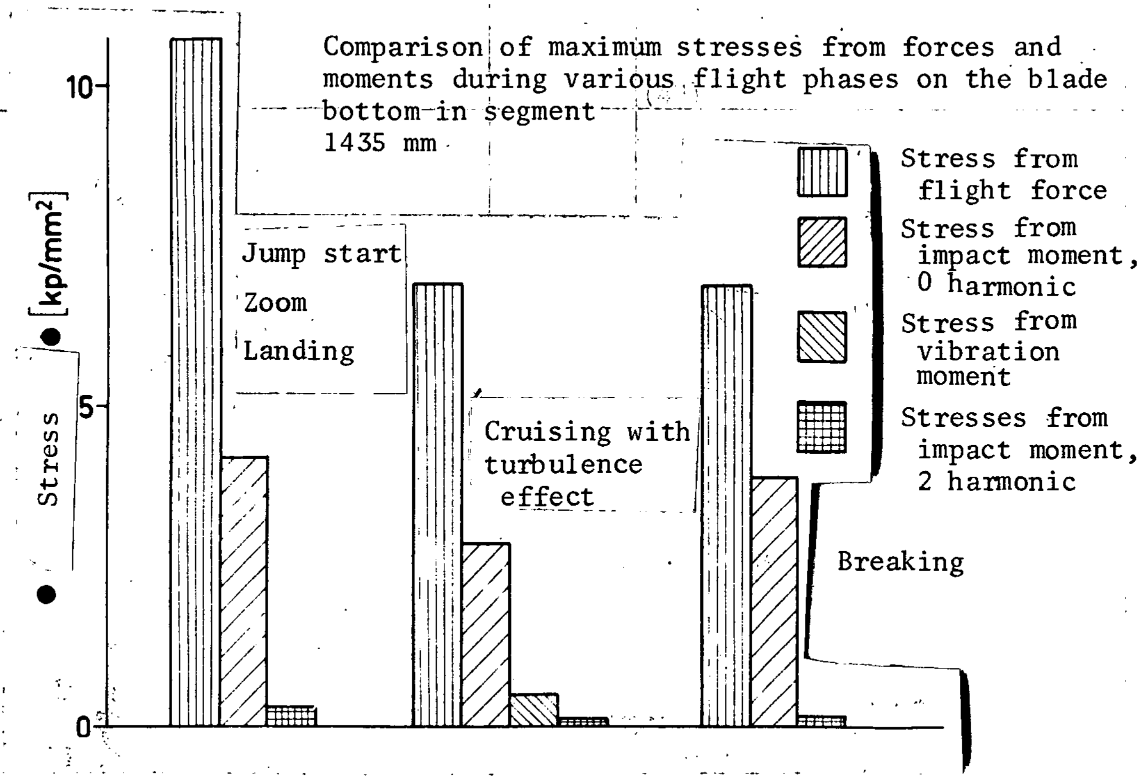

Figure 8. Comparison of Maximum Stresses on the Blade Bottom During Various Flight Phases.

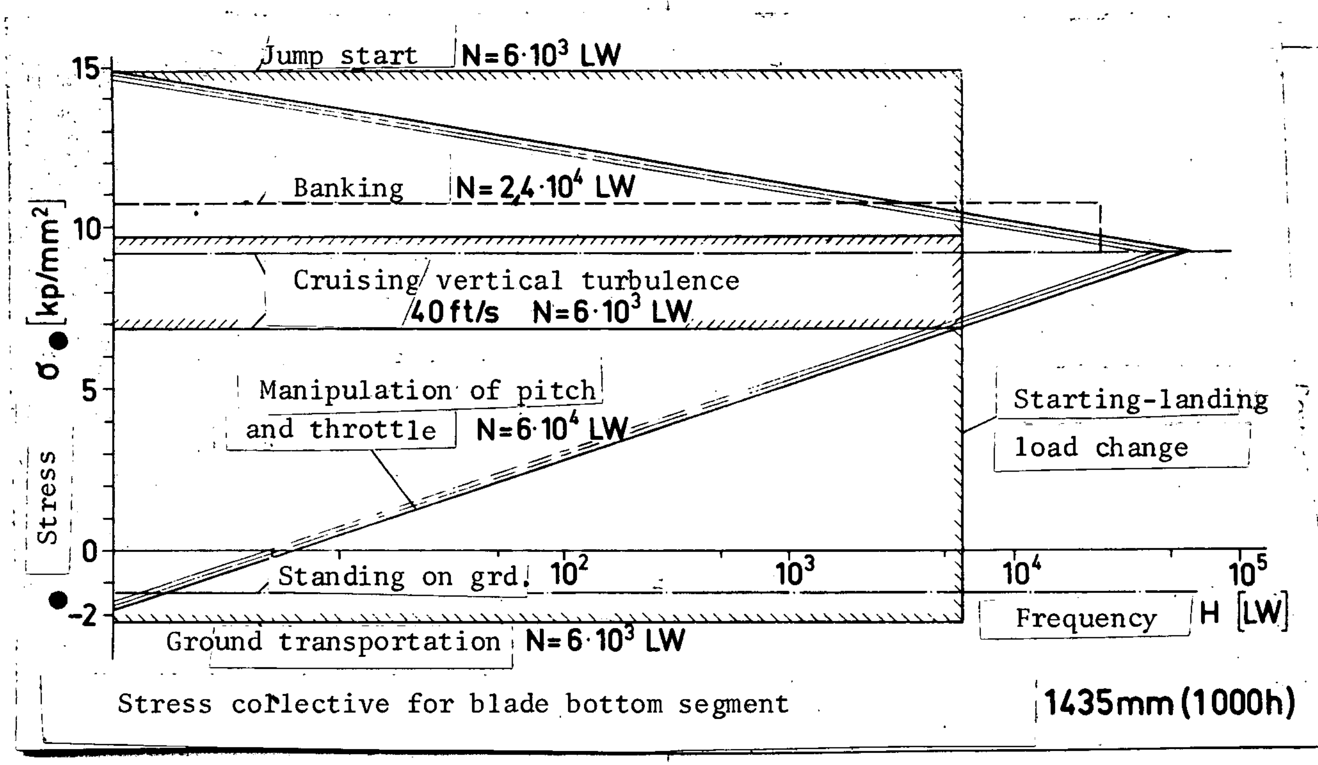

Figure 9. Stress Collective for the Panel Extension.

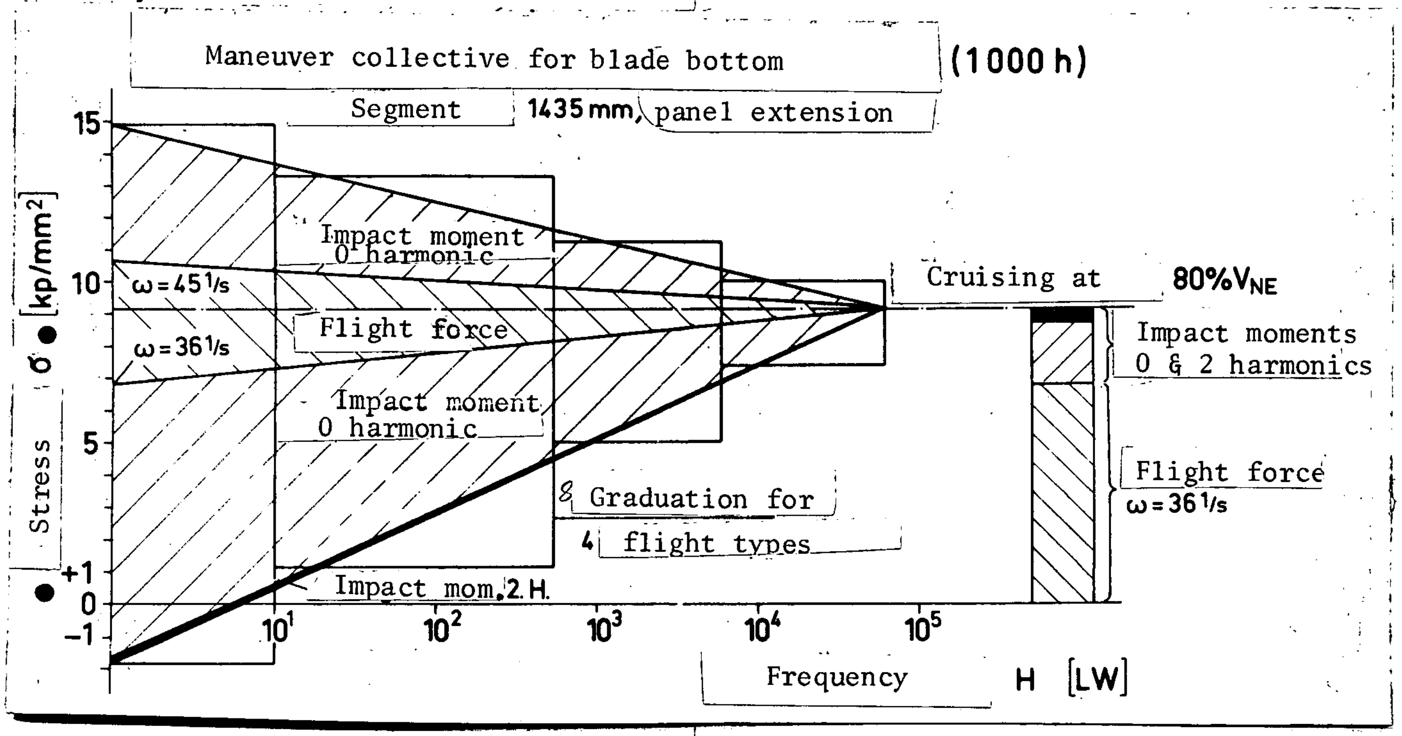

Figure 10. Maneuver Collective for Blade Bottom.

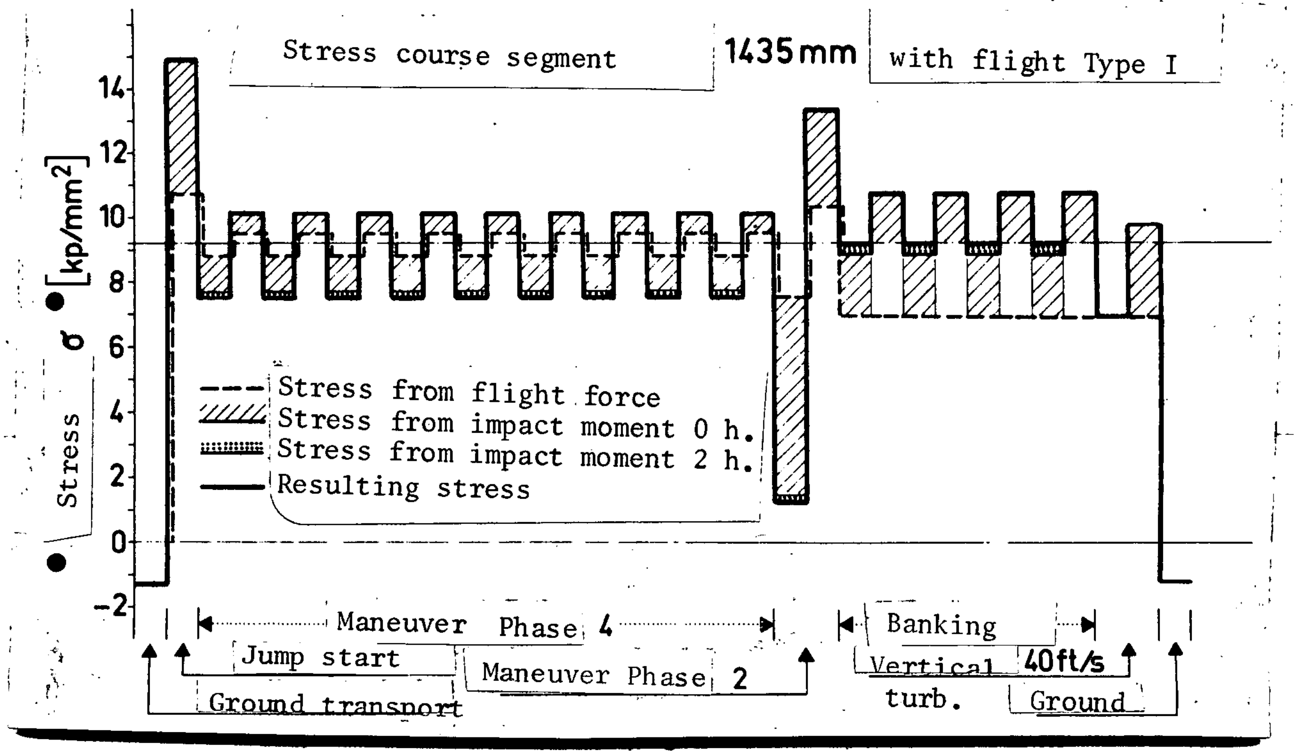

Figure 11. Example of a Stress Course.

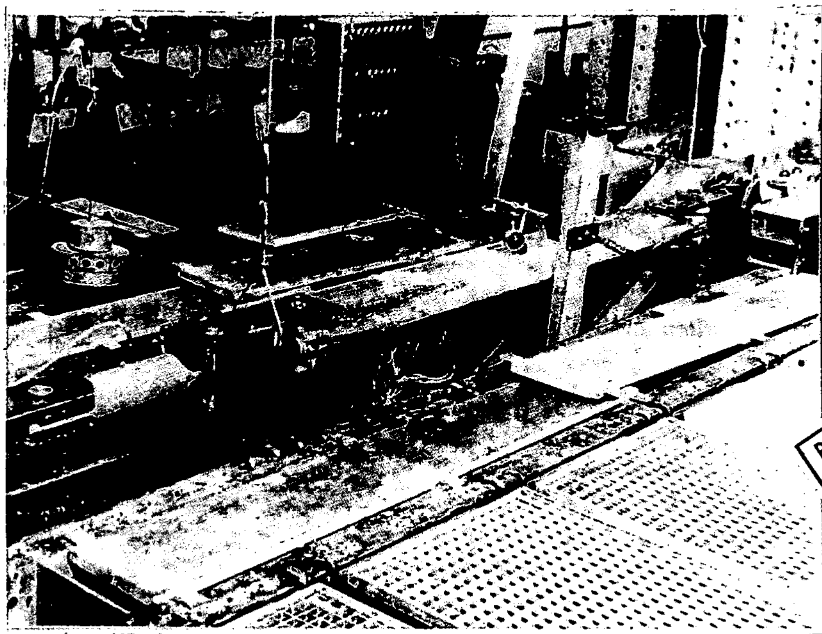

Figure 12. Test Set-Up.

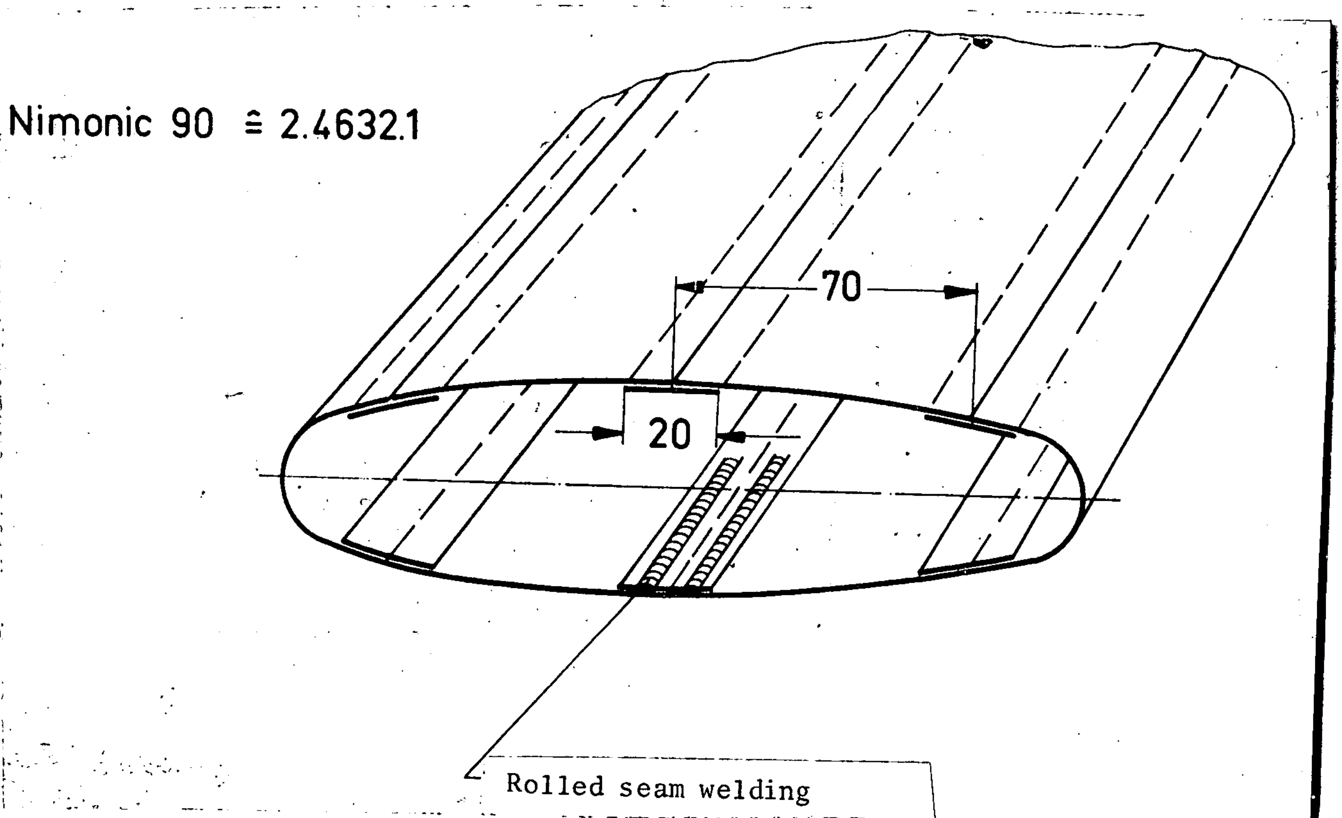

Figure 13. Construction of Gas Conduit (Rolled Seam Welding).

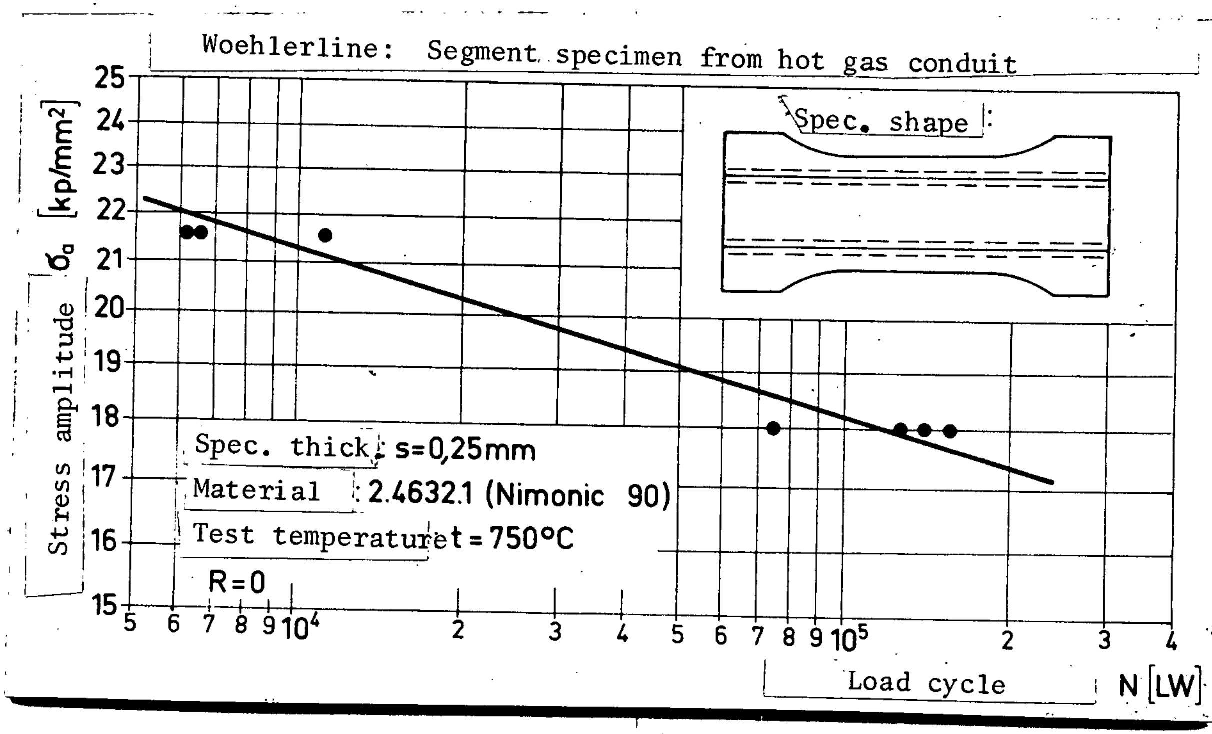

Figure 14. Hot Gas Conduit, Woehler Line.

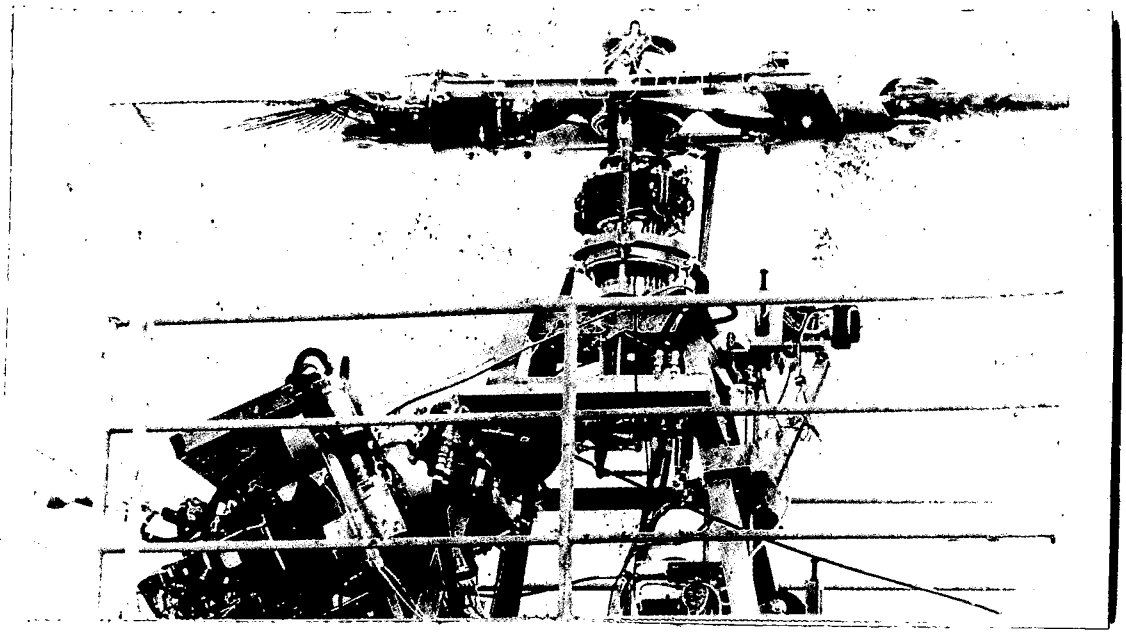

Figure 15. Rotor Testing Stand.

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